Characterization of an Dual Acoustic Receiver System for Measuring Range and Bearing to Acoustic Tags

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1 Abstract

Experiements were performed to determine the effectiveness of the Lotek RT-A Hydrophone system and if it could provide the data necessary for a particle filter to determine the location of a shark. Over the period of a few months, we tested off the Cal Poly Pier at set GPS coordinates to characterize how accurately the Lotek System can determine range and orientation. Ranges from 0-500 meters were tested with the Lotek system being in a stationary position and Lotek receiver tag being put at specified GPS coordinates. The two hydrophone rigging was then rotated a full 360 degrees to gauge if the system could accurately determine orientation and range. While signal strength is an indication of range, it was determined the Lotek device could not predict range soley on signal strength alone. Target orientation, direction of signal, was found by analyizing the incoming data which was on a scale of -9 to 9 with -9 being closest to port's 1 position and 9 being closest to port's 2 position. Target orientation data was found to be both accurate and percise. The Lotek system will be able to effectively determine direction of the target but range will have to heavily rely on the particle filter to weight all incoming data properly to determine actual range to the target.

2 Introduction

The purpose of this senior project is to test the Lotek MAP RT-A Hydrophone system and analyze the data from the system. This is part of preliminary research for a Shark Tracking Project which will use an Autonomous Underwater Vehice, AUV, to track sharks fine movement patterns. The Shark Tracking Project will span the course of 2-3 years.

2.1 Sharks

Shark Tracking will attempt to track two species of sharks. The Leopard Shark, which can be found on the Pacific Coast of North America [2] and the Great White shark, which can be found in many of the worlds ocean's but this project will concentrate on Great Whites residing off the coast of Long Beach, CA.

2.1.1 Leopard Shark

Figure 1: *Leopard Shark*

Leopard sharks, *see figure 1*, are a relatively docile species of shark. They can can grow to a length of 180 centimeters and usually can be found within 25 meters of the ocean surface on the California Coast making it a common site for snorkelers. Leopard sharks typically hide in muddy water and feed on various marine life such as worms, squid, bony fishes and rays [3]. These characteristics make the leopard shark an ideal candidate to test the Shark Tracking system without having to worry about maintaining the velocity needed to keep up with larger species of sharks.

2.1.2 Great White Shark

Figure 2: *Great White Shark swiming amongst a school of fish*

Great White Sharks, *see figure 2*, have gained infamy through popular media, most notably the Jaws movie franchise; however, despite all the publicity there are many things that are unknown about the Great White. Its true lifespan is estimated between 60-100 years [1] and can travel anywhere from 40-50km a day[5]. Great Whites are typically active around dusk and dawn with their average cruise speed increased to hunt for prey [5]. Due to its high cruising speed, the Great White has been an extremely difficult target to track and it is this project's hope to bring forth new data that can reveal more insight to the Great White's behavior patterns.

2.2 Hardware

Figure 3: *Lotek Map RT-A*

The Lotek MAP RT-A, *see figure 3*, uses hydrophones, underwater microphones, to listen for a specific frequency given off by a custom Lotek receiver tag. The use of only microphones makes hydrophones a passive system unlike sonar which can operate in both a passive mode and active mode, where the device emits a sound pulse and listens for a response. The Lotek system was designed to have a simple interface for use in marine environments such as piers and boats, *see figure 4*. The system itself is not water resistant so great care is needed to ensure it is not exposed to external elements. A small carrying case is provided which provides a small layer of protection against external elements.

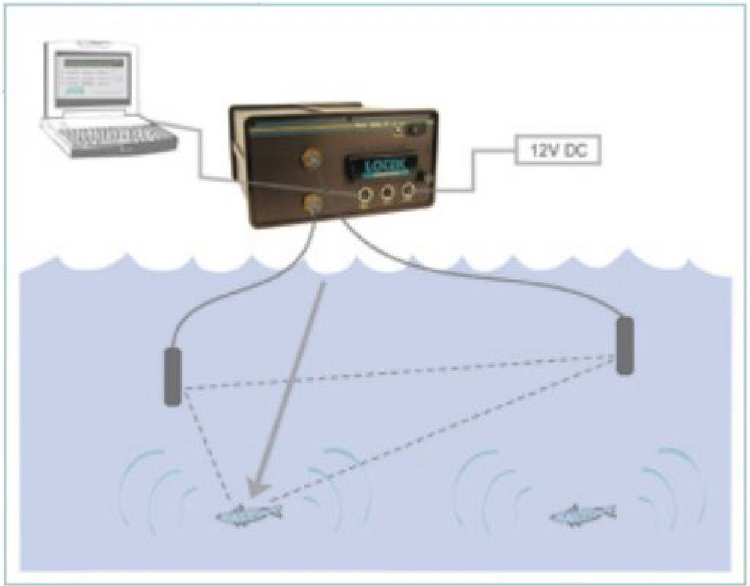

Figure 4: *Theoretical Demonstration of Deployed Lotek System*

The Lotek system interface includes:

- 2 omni-directional ports for LHP-1 hydrophone
- 1 Solid State SD memory card
- 1 RS232 port
- 12VDC power port

The hydrophones and receiver tag operates in the 76kHz frequency range [6]. This offers a theoretical max range of 500 - 1000 meters depending on outside noises, placement of hydrophones, and temperature differences [7]. The tags are designed to operate for 130-150 days depending on the rate of which transmissions are generated [7]. The Lotek system operates digitally, converting analog to digital signals, which allows for tags to be individually numbered and tracked. This means the system can track several thousand targets on the same freqeuncy [4].

2.3 Software

MapHost is the data collection tool used to extract incoming information from the hydrophones. The primary functions of the MapHost program are to connect to the MAP RT-A and SDL receiver and recover data from the receiver. MapHost can also setup the receiver in a way that all data in transfered into a standard SD memory card which can be retreived later.

2.3.1 Start the MapHost Program

Following the basic steps below will allow the connection to the Map Receiver and data recovery. A more detailed Manual may be viewed at the LAIR repository, *see section 4.5 on page 16*.

1. Connect to the Map Receiver: Tools → Connect or Ctrl-C on the Maphost window
2. Log on to the Map Reciever: click on the Gold Key on the tool bar 
3. Set the Hydrophone distance(in meters): default/optimal value 2.4m
4. Check to see if Lotek Clock is accurate. Receiver → Clock → send desired time to Lotek System
5. Make sure ID is set to OFF on the tool bar 

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6. Capture: Check "Capture" on the tool bar to begin data collection
7. End Capture: Uncheck "Capture" to stop collection

2.4 Role of Hydrophones in Shark Tracking

After characterization of the Lotek system, it will then be integrated into the Shark Tracking project. This is done by taking out the internal boards of the Lotek device and place them within the IVER, *see figure 5*. The necessary power and ports are connected to the IVER's internal components and the hydrophone connections are routed to the outside of the chassis the specifics of this process is outside the scope of this paper. With the system integrated the IVER will use data received by the hydrophone to track a shark's position in real time.

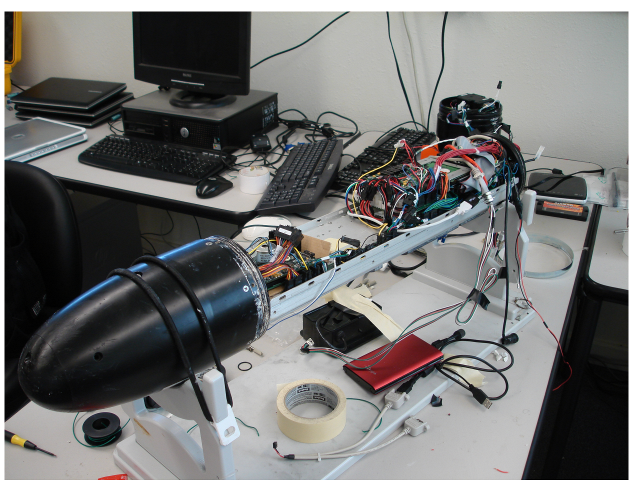

Figure 5: *Iver 1 AUV ready to place Lotek system components in.*

3 Experiments

In order to characterized the hydrophones effectiveness, several experiments were conducted on the Cal Poly Marine Sciences Pier in Avila Beach, CA.

3.1 Setup

- In order to ensure a optimal hydrophone offset distance of 2.4 meters, a PVC rigging was created to hold the hydrophones in place. This also allows for better control of the orientation of the hydrophones allowing better data of what direction the signal is coming from, *see figure 6*.
- To reduce vibrations caused by the PVC rigging, Pipe insulation was used at the connection points.
- The hydrophones are kept on the pier as data is collect via a Laptop with MapHost software installed and a RS232 port
- Tag is attached to a mooring buoy and rope with a zip tie *see figure 7*. Electrical tape is used by recommendation of Lotek Support and the zip tie offsets the tag from the mooring rope to prevent physical interference by the buoy rope. Notice that the electrical tape does not cover the rounded tip of the tag. This is the transmitter and taping it will caused interference.

Figure 6: *Hydrophone rigging with a 2.4 meter offset.*

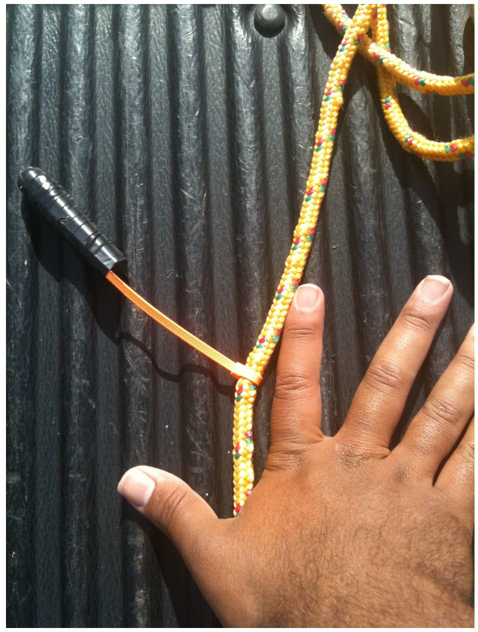

Figure 7: *Lotek tag attached to mooring buoy rope.*

3.2 Test Plan

Experiments tested two aspects of the hydrophone system: range and orientation. Because the hydrophones were limited to a stationary position, a kayak is used to place the mooring buoy with attached tag at various GPS coordinates at 25m, 50m, 100m, 150m, 300m, and 500m, *see Table 1* . At each distance the hydrophones take 3-4 minute samples at 45 degree increments in a full 360 degree arc, *see figure 8*.

Table 1: *GPS Coordinates at Cal Poly Pier at Avila Beach*

Distance	**N**	**W**
landing	35.16995	120.74100
25m	35.16995	120.74127
50m	35.16995	120.74155
100m	35.16995	120.74212
150m	35.16995	120.74262
300m	35.16995	120.74425
500m	35.16995	120.74650

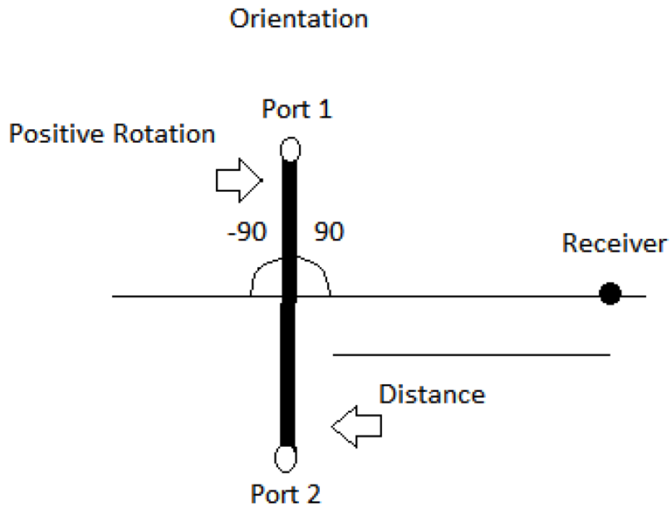

Figure 8: *Direction of positive rotation, in degrees, with respect to Lotek Receiver Tag.*

3.3 Trips to the Pier

Many trips to the pier were taken. Below is a summary with the dates of the tests and the environmental conditions: the average wind speeds (in knots) and water temperature (in degrees Fahrenheit). All tests were conducted between 8:00am and 2:00pm.

Table 2: *Wind Speeds and Water Temperatures*

Date	Wind Speed (knots)	Water Temp (F)
4 Mar 2011	1.4255	54.14
10 Mar 2011	1.0690	52.13
15 Apr 2011	3.7250	50.84
16 Apr 2011	12.7645	50.15
2 May 2011	1.2062	49.16
9 May 2011	8.1640	50.90
30 May 2011	12.7089	49.64

The water temperature varied from about 49 to 54 degrees Fahrenheit. The wind speeds varied from about 1 knot to 12.7 knots, which may cause different results than what was expected.

4 Results

The following figures and equations provided will show data collected from the different trips to the pier. Results are varied based on different environmental variables and prevention measures to reduce interference from those variables, *see section 4.4.1 on page 15.*

4.1 Signal Strength

Signal strength is determined by a variety of factors including temperature, physical interference, and recevier tag power. After analyzing the recovered data from MapHost, there is no indication there is a direct correlation between signal strength and the distance from the hydrophones to the transmiter. The graph below shows the signal strengths at different transmitter distances from the hydrophone, *see figures 9 and 10.* 25 meters has the highest signal strength between the three distances, which is expected, but 100 meters has a near identical signal strength to 50 meters.

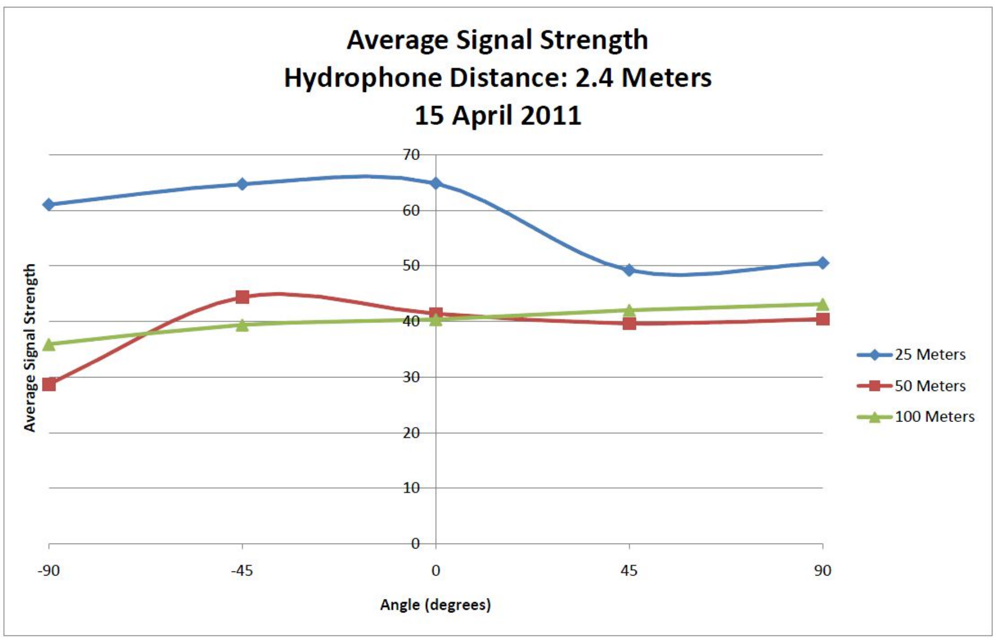

Figure 9: *Signal Strength at increasing distance on April 15, 2011 - where x is the angle and y is the average Signal Strength*

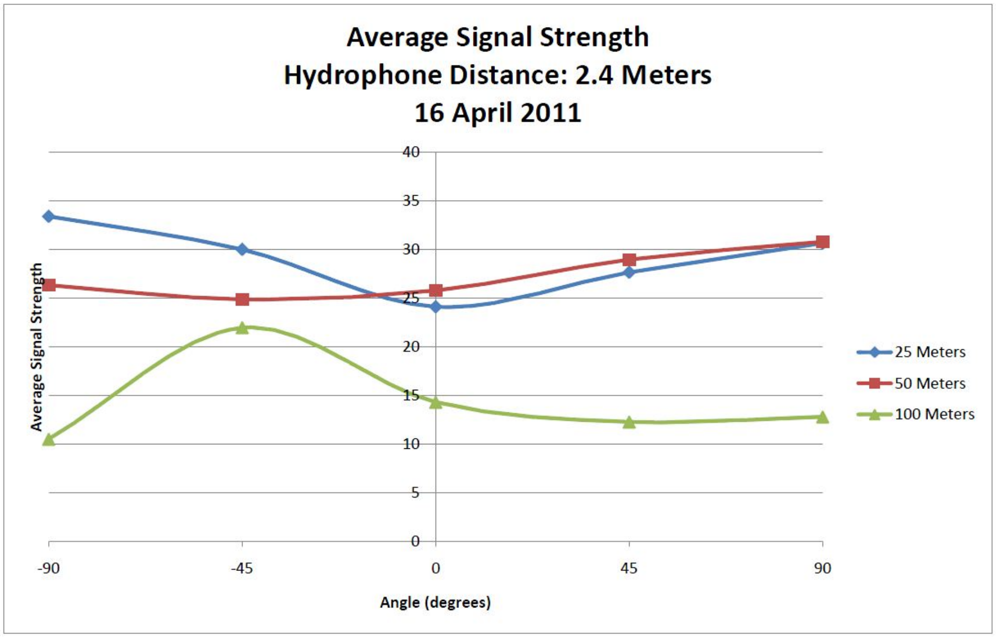

Figure 10: *Signal Strength at increasing distance on April 16, 2011 - where x is the angle and y is the average Signal Strength*

Below is an example lookup table of the standard deviations for signal strength at the different angles and distances.

Table 3: *Standard Deviation of Signal Strength Lookup Table from May 2, 2011*

Angle	**25m**	**50m**	**100m**	**125m**	**350m**
-90	15.48	8.90	12.11	8.71	3.34
-45	11.90	5.89	13.03	9.43	3.61
0	11.60	8.24	12.99	7.36	1.94
45	10.38	6.90	10.85	9.07	2.97
90	12.45	6.66	13.58	10.42	3.42

4.2 Orientation

Orientation is determine by incoming Lotek data on a scale of -9 to 9. -9 represents strongest signal comes closest to the Port 1 direction while 9 represents the signal coming directly from the port 2 direction, *see figure 11.* If the Lotek device receives insufficient data to make an accurate determination -9 or 9 are given as default values. Because there is no other indication of error, all -9 and 9s values are thrown out of the result set. This improves orientation results but leaves blindspots for targets directly in front of either port 1 or port 2.

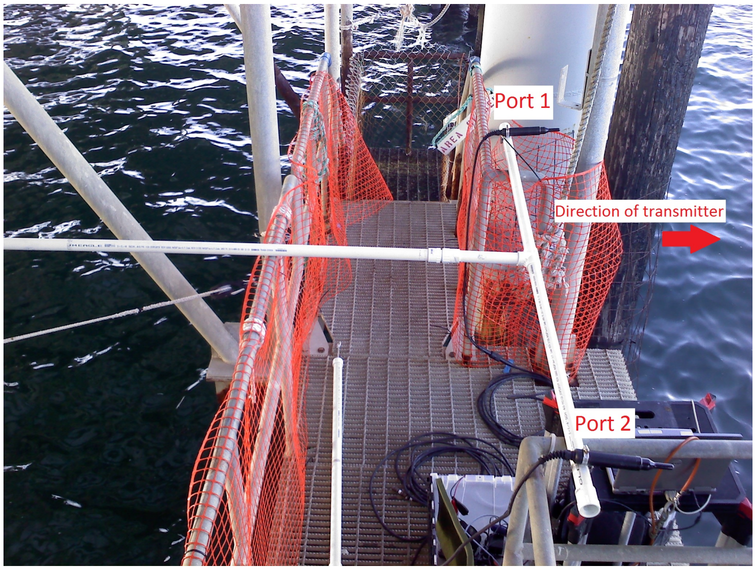

Figure 11: *Hydrophone rigging with ports 1 and 2 at 0 degree orientation.*

Using the extracted data, the frequency each port numbers can be seen in a histogram, forming a Gaussian Distribution. The following graphs are examples of the port number frequencies at different angles 100 meters away from the hydrophones.

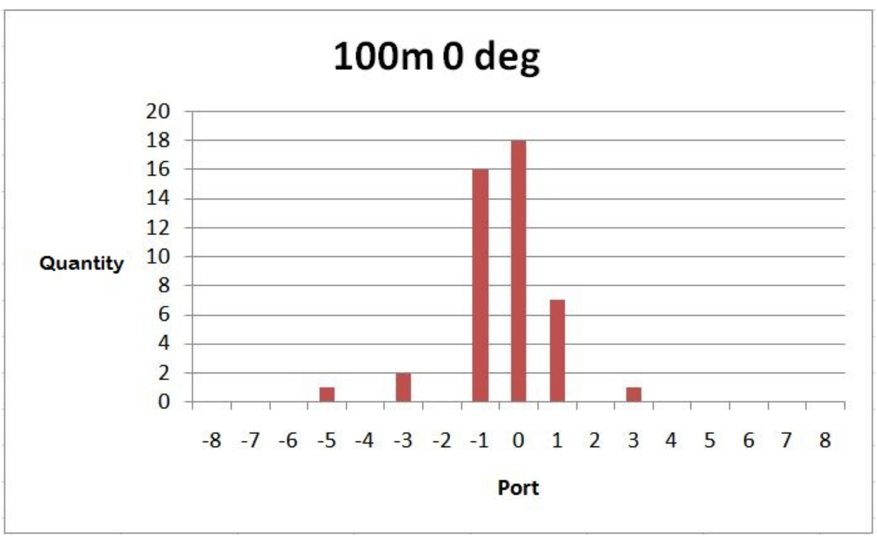

Figure 12: *Histogram of tag 100 meters away from hydrophones.*

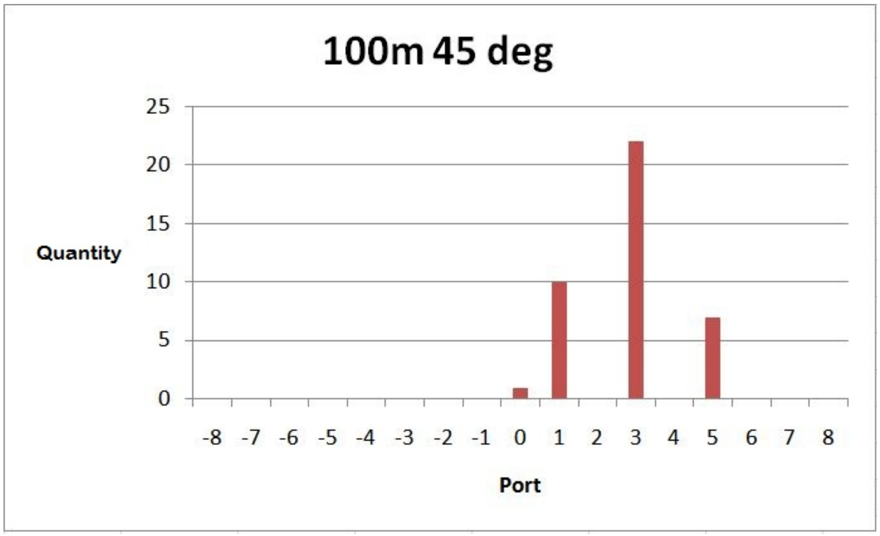

Figure 13: *Histogram of tag 100 meters away from hydrophones with 45 degree offset.*

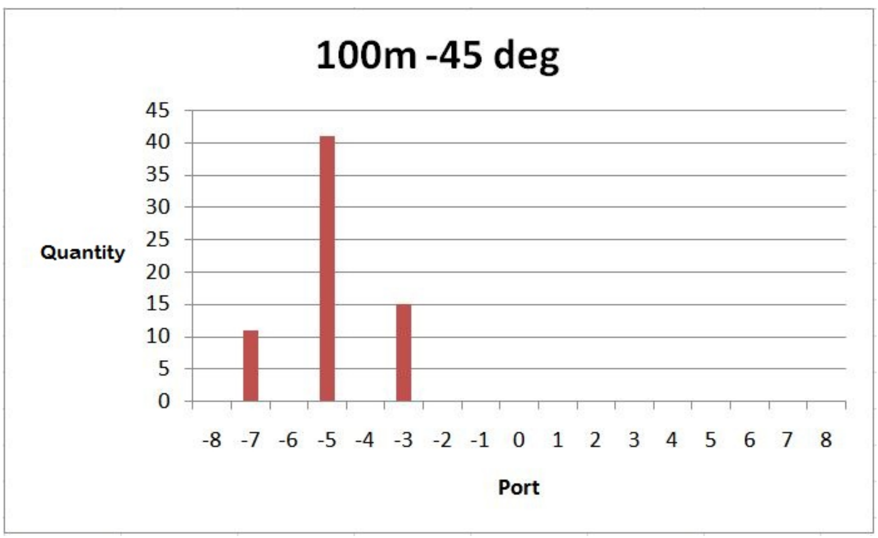

Figure 14: *Histogram of tag 100 meters away from hydrophones with -45 degree offset.*

At 0 degrees, the most frequent port number is 0. At -45 degrees, the most frequent port number is -3, whereas at +45 degrees it's 2. At -90 degrees, the most frequent port number is -8 and 8 for +90 degrees.

Below is an example lookup table of the standard deviations for port numbers at the different angles and distances.

Table 4: *Standard Deviation of Port Number (Lotek Measurement Values) Lookup Table from May 2, 2011*

Angle	25m	50m	100m	125m	350m
-90	1.469	1.027	0.622	1.999	0
-45	2.141	2.942	2.615	2.621	3.479
0	2.360	4.527	4.833	4.368	2.997
45	5.830	5.871	7.010	5.606	6.167
90	6.919	8.475	8.200	8.825	5.029

4.3 Particle Filter

In order to use the orientation data inside a Particle Filter, the orientation data needs to be graphed and a general equation extracted based on given angles. Extracting an equation from the data requred use of *Programmatic Fitting* in MATLAB whose source can be found in the repository, *see section 4.5 on page 16*. The following figures and table are results from the latest successful set of data collection.

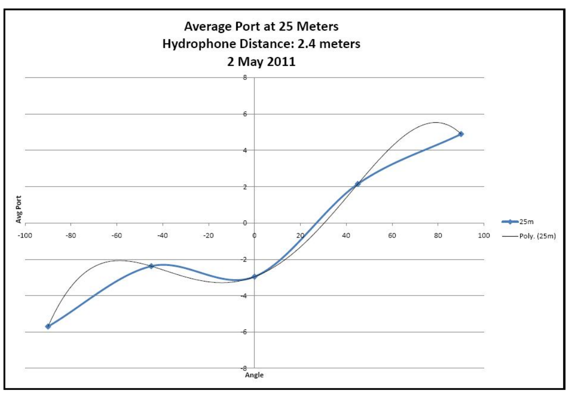

Figure 15: *Average Orientation with regressed trendline at 25m.*

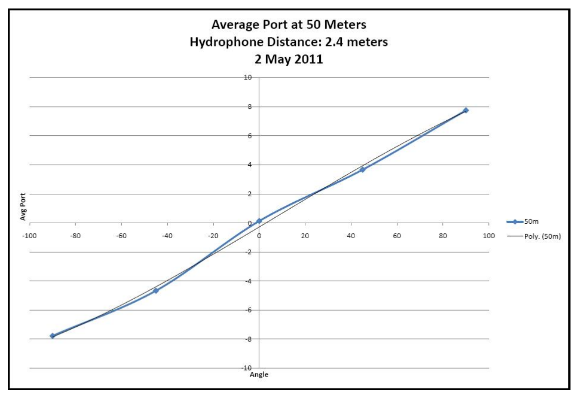

Figure 16: *Average Orientation with regressed trendline at 50m.*

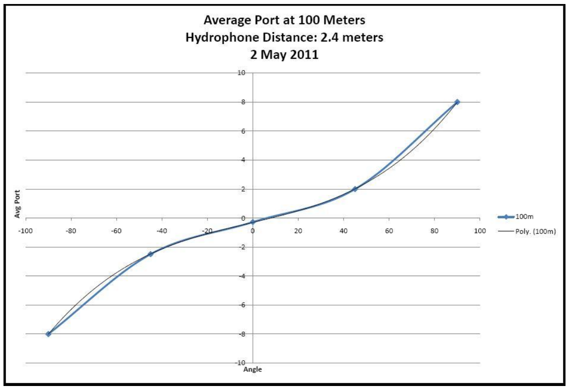

Figure 17: *Average Orientation with regressed trendline at 100m.*

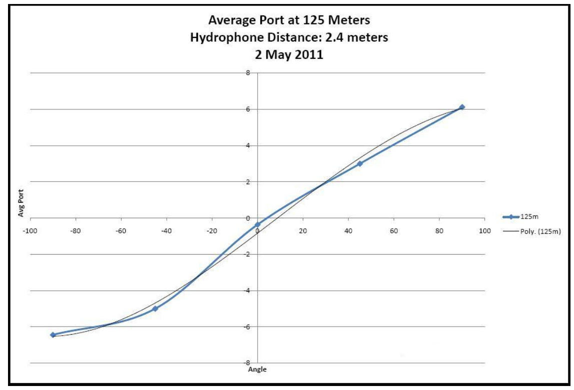

Figure 18: *Average Orientation with regressed trendline at 125m.*

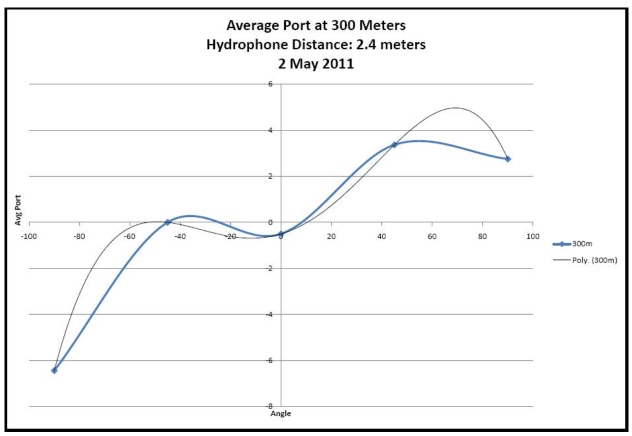

Figure 19: *Average Orientation with regressed trendline at 300m.*

Table 5: *Extracted Equations from Regression analysis from -90 to 90 degrees - where x is the angle and y is the average port number (Lotek measurement value)*

Distance	Equations
25m	$y = -2 \times 10^{-7}x^4 + 1 \times 10^{-6}x^3 + 0.0018x^2 + 0.0474x - 2.9524$
50m	$y = -1 \times 10^{-6}x^3 + 2 \times 10^{-5}x^2 + 0.0947x - 0.2757$
100m	$y = 6 \times 10^{-6}x^3 + 4 \times 10^{-5}x^2 + 0.0369x - 0.3015$
125m	$y = -3 \times 10^{-6}x^3 + 7 \times 10^{-5}x^2 + 0.0952x - 0.8337$
300m	$y = -2 \times 10^{-7}x^4 + 2 \times 10^{-6}x^3 + 15 \times 10^{-4}x^2 + 0.0329x - 0.5$

4.3.1 Sample Calculations

In order to analyze and interpret the data, different calculations are required. Averages for both port numbers and signal strength at different angles and distances were taken to get an initial understanding of the data.

$$\mu = \frac{1}{N}\ \Sigma_N^{i=1}(x_i)$$

where

μ is the mean or average

N is the total number of inputs(x)

x_i is the input at i
To see how much variation there is from the port number average and signal strength average, the standard deviation is used.

$$\sigma = \sqrt{\Sigma_N^{i=1}(x_i - \mu)^2}$$

where

σ it the standard deviation

N is the total number of inputs(x)

μ is the mean or average

x_i is the input at i
With the standard deviation, a lookup table is developed for the different hydrophone angles at each distance. Modeled variences can easily be calculated, σ^2, using the standard deviation which will be used for the particle filter.

4.4 Error Analysis

Part of performing any kind of test requires an error analysis. There is no such thing as perfect data, therefore there must be a reason for data to differ from one day to another. One main factor would cause any error is interference.

4.4.1 Interferences

Interference from outside factors can cause error during the data collection. Rocks and other objects submerged in the ocean, such as the pier's pillars, can block the transmitter's signal causing the hydrophones to output 9/-9. Different water temperatures, a sudden change in temperature between the Lotek System and tag, may also produce different data results. The change in temperature effects the properties of sound causing it to speed up or slow down depending on how warm or cold the water is. Another factor that can attribute to poor data is strong currents or waves. Strong currents can cause the bouy attached to the transmitter to drift slightly from its original position. In addition, strong currents twist the hydrophone rig skewing the data results if the operator does not keep the rig stationary. Strong waves cause additional noise in the ocean and the Lotek System which can also effect results.

Interference can be handled several ways. Going out on a calm day and knowing water temperatures can help you avoid many issues. In addition, the deeper the hydrophones are deployed the less chance of surface noise such as waves and boats can effect the Lotek Sytem. Ensuring proper insulation around the hydrophones will keep vibrations from the rigging itself from interfering with results. Each preventive measure mentioned has helped increase range from a initial 100 meters to 400-500 meters.

4.5 Repository

All related data to the Lotek hydrophones can be found on the LAIR wiki page svn repository: *https://wiki.csc.calpoly.edu/svn/LAIR*. A summary of the directory can be found bellow.

- Lotek Manuals: Manuals for both MAP RT-A Receiver and MapHostv4 software.
- Paper: Associated Source files and images related to this document.
- Pier Checklists: Checklists for Kayak and Hydrophone Deployment at Cal Poly Pier
- PierOpenHouse: Documents and images related to Pier open house on April 23, 2011.
- Tests data: All Raw data and graphs. See associated README files for daily conditions and tests performed.

Any questions about the repository can be directed to Victoria Campana: vcampana@calpoly.edu and Justin Knight: jsknight@calpoly.edu.

5 Conclusion

This project was a great learning experience. The most challenging part of the project was how we were going to initially set up our equipment to perform tests. For example, our original plan was to test the hydrophones parallel to the pier, but we later found out that we were getting interference from the pier's pillars. We then switched to testing the hydrophones perpendicular to the pier. This caused another road block in our testing, we needed to obtain a California boating license to perform those experiments. Once that was completed, we were able to carry on with the experimentation.

As we started going to the pier on a regular basis, we realized that there are always going to be good days and bad days, as far as testing is concerned. Our results not only depended on how well the hydrophones were responding to the transmitter, but also the environment which can go from a calm day to 10 knot winds within a few hours.

After performing many tests at the pier and analyzing data from each trip, we were able to grasp an understanding of the output Lotek produces and use it as useful information for the promising future project. It is our belief that the Lotek system can provide the necessary information to integrate into a particle filter to allow an AUV to track sharks.

References

[1] Great white shark. http://www.enchantedlearning.com/subjects/sharks/species/Greatwhite.shtml, May 2011.

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